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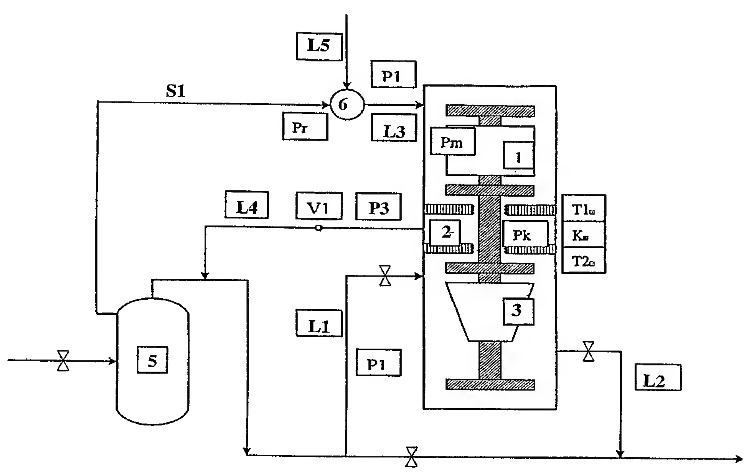
(54) **Title:** PRESSURE AND LEAKAGE CONTROL IN ROTATING EQUIPMENT FOR SUBSEA COMPRESSION



(57) **Abstract:** The present invention defines a subsea compression module with an electric motor (1) in a first pressure housing for being pressurized with a pressure (Pm) and a compressor (3) in a second pressure housing with a suction pressure (P1). A third intermediate pressure housing (2) is provided between the motor (1) and the compressor (3), and a seal (T1) for the output shaft of the motor, seals between the pressure housing of the motor and the third intermediate pressure housing. A seal (T2) for the input shaft of the compressor (3) seals between the intermediate pressure housing (2) and the compressor (3). A connection (K) is provided between the motor 1 and the compressor (3) in the third intermediate pressure housing (2). A method for maintaining a controlled environment for a sub sea compression module is also provided.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

"Pressure and leakage control in rotating equipment for subsea compression"

The present invention relates to a subsea compression system for well fluid boosting by compressing hydrocarbon gases and pumping hydrocarbon liquids. More particularly, the invention relates to how internal leaks in the compression module should be handled to ensure a suitable environment for the various components, and how to ensure that no contamination leaks from the module into the environment external of the compression module or system, or builds up inside the components.

The system is particularly developed for deep sea compression stations.

An offshore gas field may be developed with seabed installations, which are tied back to terminals onshore or to an existing platform. The seabed installation comprises one or more production templates where each template produces well fluids through manifold headers, which are connected to one or more pipelines. The pipelines transport well fluids to an onshore terminal, an offshore platform or any other receiving facility for further processing. Processed gas and condensate are exported to the market. One or more umbilicals for power, control and utility supplies are installed from the receiving facility to the subsea installation.

For the initial production phase, well fluids may flow into the receiving facility by means of the reservoir pressure. Later in the productions phase or at start-up of the production, well fluid boosting is required in order to maintain the production level and to recover the anticipated gas and condensate volumes. This is may be performed by a subsea compressor assembly.

Subsea compressors for this purpose with electric motors that requires a dry environment, and that utilizes a pressurised, gas filled motor housing are for instance disclosed in Norwegian Patents Nos. NO 172075, NO 173197, Norwegian Patent Application No. 2001 5199 as well as Norwegian Patent Application No. 2003 3034.

These publications disclose the use of gas filled electric motors where avoiding corrosion and other problems that are related to separation of hydro carbon condensates and water in liquid form in the motor, is considered.

Norwegian Patent Application 2003 3034 discloses a gas compressor module with pressure housing. The module includes an electric motor and a compressor connected with at least one shaft. The compressor and motor are isolated by means of at least one seal. The shaft is carried by magnetic bearings. The application describes volume and pressure control of the gas flowing into the motor, and the use of a supply of dry hydrocarbon gas. Furthermore means for sensing the pressure in the inlet and outlet is described, whereby based on the measured pressure, the pressure and volume regulator controls the pressure of gas from the supply for injection into the motor housing.

The application does however not consider how to handle the gas that leaks out around the shaft of the motor and the shaft of the compressor, and accordingly there is a need for an apparatus where these leaks can be taken care of in an environmentally friendly way. Furthermore it is an object of the invention to allow flow out through the seals around the input shaft of the compressor, and prevent this flow from entering into the motor housing for instance through the seals around the output shaft of the motor. Yet another object of the invention is to prevent the fluids leaking out of the seals to accumulate, or to build up a pressure with a possible consequence that the fluids leaks back into the components.

This is achieved with the system according to the present invention providing a subsea compression module with an electric motor in a first pressure housing for being pressurized with a pressure Pm and a compressor in a second pressure housing with a suction pressure P1. A third intermediate pressure housing is placed between the motor and the compressor, and a seal is provided on the output shaft of the motor, sealing between the pressure housing of the motor and the third intermediate pressure housing. Furthermore a seal is provided on the input shaft of the compressor, sealing between the intermediate pressure housing and the compressor. The shaft of the motor and shaft of the compressor are connected in the third intermediate pressure housing.

The intermediate pressure housing may be provided with a fluid connection, and may be connected to a pressure sensor. A pressure Pk in the intermediate pressure housing can be controlled to be lower than the pressure Pm in the motor pressure housing and higher than the suction pressure P1 of the compressor.

The fluid connection of the intermediate pressure housing may communicate with the gas connections at the low pressure side of the compressor such that the fluid connection of the intermediate pressure housing is in connection with the gas connections at the suction side of the compressor and / or a scrubber upstream of the inlet of the compressor.

A supply line with a pressurized gas from a liquid separator may supply the pressure to the motor pressure housing. A bleed line may connect the coupling or intermediate pressure housing with the liquid separator/scrubber. A pressure controller or pressure regulator in connection with the supply line may maintain the pressure Pm in the motor or first pressure housing. The pressure in the supply line may be equal to or above the necessary pressure Pm in the first housing. The pressure regulator may be placed between the supply line and an inlet line of the first pressure housing, for controlling the pressure Pm of the gas from the supply line to the first pressure housing.

The intermediate pressure housing may be connected to the inlet fluid separator or scrubber for reintroducing the fluid from the intermediate pressure housing.

The pressure in the first pressure housing Pm may be controlled to be above than the pressure P1 in the inlet fluid separator.

A pressure regulator may control the pressure Pm to ensure that it is above the inlet pressure P1 of the compressor and the pressure Pk in the intermediate pressure housing.

A method for maintaining a controlled environment for a subsea compression module with a motor in a first pressure housing and a compressor in a second pressure housing includes the steps of leading a dry gas from a source to a pressure regulator and feeding the first pressure housing with the dry gas at a first pressure Pm.

The source of dry gas may be a well stream treated in a fluid separator, and a substantially dry gas may be extracted from this separator. A dry gas from a source as mentioned above can be led to the pressure regulator feeding the first pressure housing with the dry gas. A certain leak is allowed through a seal around an output shaft of the motor into a third intermediate pressure housing. The pressure of the first pressure housing may be controlled to a pressure above the pressure in the third pressure housing, and pressure from the third pressure housing pressure may be bled off.

A well stream may be provided to the inlet of the compressor at an inlet pressure. A certain leak may be allowed through a seal around an input shaft on the compressor also into the intermediate pressure housing. The pressure Pk of the intermediate pressure housing may be controlled to be above the inlet pressure P1 of the compressor.

The pressure Pm in the first pressure housing may be above the inlet pressure P1 of the compressor.

The fluid from the third pressure housing may be lead to the inlet of the compressor.

A subsea compression station where this system may be included may comprise the following modules and parts:

one or more compressor trains,
one or more circuit breaker modules,
inlet and outlet manifolds,
inlet coolers (if supply pipelines not are sufficient for cooling the well stream),
inlet sand trap (for accidental sand production),
parking location for main transformer and power umbilical termination head,
process system,
control system.

The compressor train may include:
compressor module,
compressor variable speed drive (VSD),
anti surge valve and actuator,
anti surge cooler,
separator/scrubber module,
pump module,
pump VSD (variable speed drive),
remote and manually operated valves,
interconnection piping,
control system including control modules.

The compressor may be driven directly by high-speed motor. The electric motor may be cooled with a hydrocarbon gas at a pressure controlled to be equal or close to the suction pressure of the compressor. The gas source may be the well stream supplied to the subsea compression station, and should be conditioned prior to entering the electric motor. The system will of course also work with a gas commonly used for pressurizing electric components. The system may utilize magnetic bearings for each of the subsea compressor modules, or magnetic radial and axial bearings as well as run-down bearings. The material properties of the compressor unit should be suitable for operation with relevant contents of H_2S and CO_2.

The compressor and the material properties should be designed for the liquid fractions and solids content coming with the gas stream from the upstream separator. The size and distribution of liquid droplets and solids particles are dependent on the separator design, and the separator should be designed to bring the content of liquids and solids down to an acceptable level. The compression system may be designed to handle the continuous fines/sand production. The rotating equipment may be protected against wear and degradation from solids to ensure high efficiency, long life and reliability.

The compressor may include an anti-surge control recycle line designed for full recycle flow at maximum conditions speed (105%). The anti-surge control valve may be an electrically actuated, axial stroke design and may be located close to the compressor discharge at high point. An anti-surge recycle cooler may be included downstream of the anti-surge valve in the recycling pipe loop. The compressors may have a discharge pipe equipped with a remote operated isolating valve. A non-return valve may be fitted in the compressor discharge pipe upstream of the isolation valve.

The separator separates liquid/solids from the gas which in turn is ingested into the pump and compressor, respectively. The separator is designed to separate liquids and solids from the gas flow to avoid excessive erosion of the

compressor, and to ensure clean dry gas to the various housings, including the motor housing and the compressor housing. The separator is designed to ensure that solids not are clogged or undesirably accumulated anywhere in the separator.

The compression station may include various process coolers such as an anti surge cooler/recycle cooler to cool the gas flow in the antisurge line (compressor recycle loop) and input coolers to cool the flow from templates.

The compressor station may have tie-in connections for well fluid discharge, and may include ROV operated valves for routing of the well fluid to the different pipelines.

The well fluid from tied-in production templates may be distributed to a separator equipped with a hydraulic actuated isolation valve in the inlet pipe. The well stream may further be routed via the compressor by-pass line before compressor start up and the by-pass valve may be closed when the compressors are brought into operation. Most of the solids from the production may be removed in separators. Sand/fines/solids entering the compression station will be separated out in the separator and transported via the liquid pump to the discharge pipeline. However, a sand trap for accidental sand production may be used to remove sand from the inlet well fluid. Gas demisting and gas-liquid separation may be performed by the use of scrubbers.

Brief description of the enclosed drawing:

Fig. 1 is a schematic representation of a subsea compression module according to one embodiment of the invention.

Detailed description of embodiments of the invention with reference to the enclosed figure:

Fig. 1 shows a subsea compressor module according to an embodiment of the invention. The module includes an electric motor 1, a coupling or intermediate

chamber 2 and a compressor 3. The motor 1 is connected to the compressor 3 with a coupling in the intermediate chamber 2. Alternatively motor 1 and the compressor 3 may be connected to the same shaft. The coupling may for instance be a flange or any other suitable joint. Alternatively the intermediate chamber 2 may include a transmission if a certain ratio is needed between the motor 1 and the compressor 3.

On the output shaft of the motor, where this enters the intermediate chamber, a seal T1 is included. Similarly, a seal T2 is provided on the input shaft of the compressor where this shaft enters the intermediate chamber 2.

An inlet liquid separator 5 typically consisting of inlet cyclones and guide vanes receives a well flow and delivers a substantially dry gas to the compressor which compresses the gas.

A pressure regulator 6 controls the pressure of the gas from a source through line L5 and leads the gas through a line L3 into the motor at a pressure Pm. The gas source may be an umbilical from an offshore platform, a line from an onshore installation, gas tanks in the area, a conditioning unit providing dry gas from the well stream, or any other suitable source. The source must however be able to provide gas to the pressure regulator 6 at a pressure equal to or above the required motor pressure Pm.

A pressure sensor in the inlet liquid separator 5 gives a signal to the pressure regulator 6 through a suitable connection S1, enabling the pressure regulator 6 to control the pressure Pm in the motor to be above the pressure in the inlet liquid separator 5, and hence the pressure Pk in the intermediate chamber 2. The actual pressure Pm in the motor housing may also be monitored to ensure that this pressure Pm is within the specified range in relation to the pressure in the inlet fluid separator 5.

The line L4 connects the intermediate chamber 2 to the liquid separator.

A check valve V1 on the line L4 between the intermediate chamber 2 and the inlet fluid separator 5 ensures no inflow of fluid into the intermediate chamber 2 in the case of off design conditions.

A line L1 from the well supplies gas to the compressor 3 at a suction pressure P1. The compressor delivers a compressed outlet fluid flow through line L2.

The pressure Pk in the intermediate chamber is governed by the pressure Pm in the motor housing controlled by the pressure regulator 6 and the pressure in the inlet separator. The pressure Pk in the intermediate chamber 2 is higher than the suction pressure P1 of the compressor. A pressure higher than the suction pressure P1 of the compressor 3 and higher than the pressure Pk in the intermediate chamber will however build up around the input shaft of the compressor 3 and ensure fluid flow out of the seal T2 around the input shaft of the compressor 3 and into the intermediate chamber 2. The pressure build up around the input shaft the compressor seal T2 is exposed to, is an inherent feature of axial compressors.

The motor 1 and the compressor 3 are connected by a coupling K placed inside the intermediate chamber 2. The compressor 3 is connected to the inlet line L1 for receiving gas and the outlet line L2. The pressure housing for motor 1 includes electric connections in addition to the lines L3 for supply of clean/conditioned gas.

The intermediate chamber 2 isolating the motor 1 and the compressor 3 with seals T1 and T2 respectively, receives gas leaking from the compressor 3, and/or a saturated pressure during normal operation or in the case of a shut-down of the subsea compressor module. From the motor side, the intermediate chamber 2 can receive gas that leaks from the motor 1 in that the pressure in the motor Pm is above the pressure Pk in the intermediate chamber 2 and above the suction pressure P1 of the compressor.

To ensure that the pressure in the motor housing is higher than the pressure in the intermediate chamber 2, pressure sensors or probes connected to the inlet liquid separator 5 and to the motor chamber for monitoring the respective pressures and the pressure regulator 6 controls the pressure of the gas in the motor housing. This ensures that the pressure Pm in the motor housing is maintained at a higher level than the suction pressure P1 of the compressor and the pressure Pk in the intermediate chamber. The gas in the intermediate chamber is returned to the suction side or the liquid separator 5 to prevent collection of impure fluid in the system.

The seals T1 and T2 may be of various types, and may for instance be brush seals or labyrinth seals, both types being well known within the field.

Claims:

1. A subsea compression module with an electric motor (1) in a first pressure housing, a compressor (3) in a second pressure housing, **characterized in**
a third intermediate pressure housing (2) between the motor (1) and the compressor (3);
a seal (T1) for an output shaft of the motor (1), sealing between the first pressure housing and the third intermediate pressure housing (2);
a seal (T2) for the input shaft of the compressor (3), sealing between the intermediate pressure housing (2) and the second pressure housing; and
a connection between the shaft of the motor (1) and the shaft of the compressor (3) in the third intermediate pressure housing (2).

2. The subsea compression module according to claim 1, further comprising a fluid connection (L4) on the intermediate pressure housing (2);
a pressure sensor for monitoring the pressure in the intermediate pressure housing (2); and
a pressure regulator (6) adapted to ensure that a pressure (Pk) in the intermediate pressure housing is lower than the pressure (Pm) in the first pressure housing and higher than a suction pressure (P1) of the compressor (3).

3. The subsea compression module according to claim 2, wherein the fluid connection (L4) of the intermediate pressure housing (2) is in connection with the suction side of compressor (3) and/or scrubber (5).

4. The subsea compression module according to claim 1, wherein a supply line (L5) with a pressurized gas at a pressure equal to or above the necessary pressure (Pm) in the first housing supplies the pressure (Pm) to the first pressure housing.

5. The subsea compression module according to claim 1, wherein the pressure regulator (6) is placed between the supply line (L5) and an inlet line (L3) of the first pressure housing, for controlling the pressure (Pm) of the gas from the supply line (L5) to the first pressure housing.

6. A method for maintaining a controlled environment for a subsea compression module with a motor (1) in a first pressure housing and a compressor (3) in a second pressure housing,
characterized in that
it includes the following steps:
leading a dry gas from a source (L5) to a pressure regulator (6) feeding the first pressure housing with the dry gas at a first pressure (Pm);
allowing a certain leak through a seal (T1) around an output shaft of said motor (1) into a third intermediate pressure housing (2);
controlling the pressure (Pm) of the first pressure housing to a pressure above the pressure (Pk) in the third pressure housing (2); and
bleeding off pressure (Pk) from the third pressure housing (2).

7. The method according to claim 6, further including the steps of:
providing a well stream to an inlet of the compressor (3) at an inlet pressure (P1);
allowing a certain leak through a seal (T2) around an input shaft on said compressor (3) into said intermediate pressure housing (2);
providing a pressure (Pk) of the intermediate pressure housing above the inlet pressure (P1) of the compressor.

8. The method according claim 6, further comprising controlling the pressure (Pm) into the first pressure housing to a pressure above the inlet pressure (P1).

9. The method according claim 6, further comprising conditioning a part of the well stream to supply the source (L5) with a dry gas.

10. The method according claim 6, further comprising leading the fluid from the third pressure housing (2) to the inlet (L1) of the compressor.

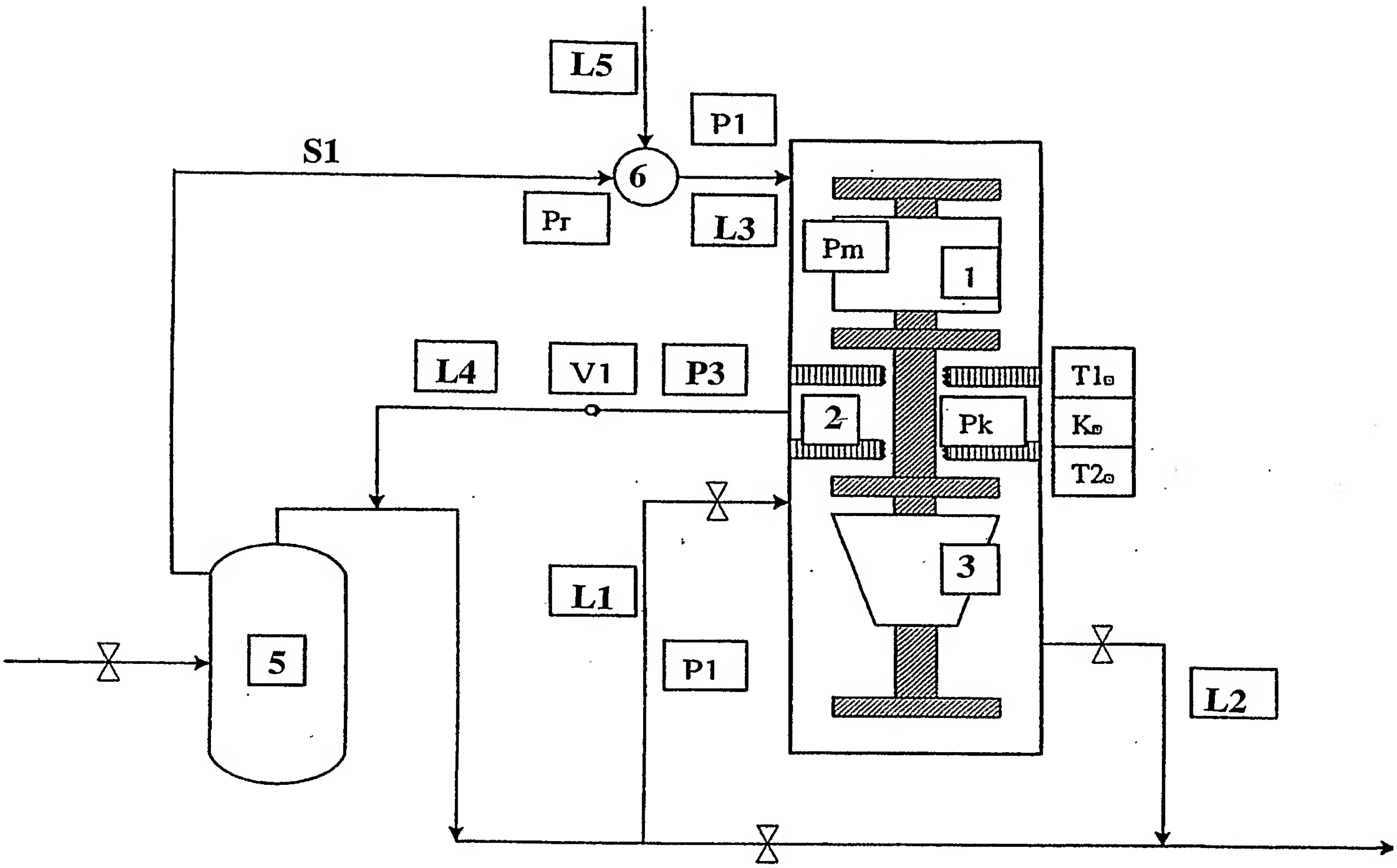

Fig. 1

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: E21B, F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9214061 A1 (KVAERNER ROSENBERG A.S. ET AL), 20 August 1992 (20.08.1992), figures 1,2, claims 1-6 --	1-10
A	WO 03035225 A1 (KVAERNER EUREKA AS), 1 May 2003 (01.05.2003), figure 1, abstract --	1-10
A	WO 2005003512 A1 (KVAERNER OILFIELD PRODUCTS AS), 13 January 2005 (13.01.2005), page 6, line 10 - line 17, figure 3 -- --------	1-10

☐ Further documents are listed in the continuation of Box C.   ☒ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
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Paper copies can be ordered at a cost of 50 SEK per copy from PRV InterPat (telephone number 08-782 28 85).

Cited literature, if any, will be enclosed in paper form.

INTERNATIONAL SEARCH REPORT
Information on patent family members

26/01/2007

International application No.
PCT/NO2006/000407

WO	9214061	A1	20/08/1992	AU	1265192	A	07/09/1992
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				EP	0670965	A	13/09/1995
				NO	172075	B,C	22/02/1993
				NO	173890	B,C	08/11/1993
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				RU	2006102966	A	27/07/2006
				US	20060157251	A	20/07/2006

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APPL-DATE: November 10, 2006

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ABSTRACT:

CHG DATE=20070525 STATUS=O>The present invention defines a subsea compression module with

an electric motor (1) in a first pressure housing for being pressurized with a pressure (Pm) and a compressor (3) in a second pressure housing with a suction pressure (P1). A third intermediate pressure housing (2) is provided between the motor (1) and the compressor (3), and a seal (T1) for the output shaft of the motor, seals between the pressure housing of the motor and the third intermediate pressure housing. A seal (T2) for the input shaft of the compressor (3) seals between the intermediate pressure housing (2) and the compressor (3). A connection (K) is provided between the motor 1 and the compressor (3) in the third intermediate pressure housing (2). A method for maintaining a controlled environment for a sub sea compression module is also provided.